5.1 Current generation in a magnetic field

Let's begin Naughty balls

1 Induced e.m.f. and current

2 Direction of induced e.m.f. and current

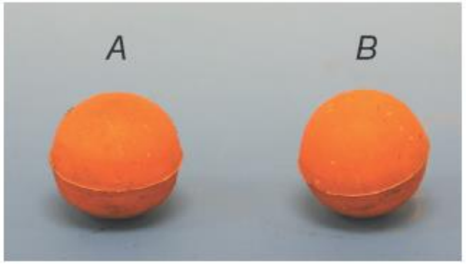
Check-point 1

3 Magnetic flux and flux density

Check-point 2

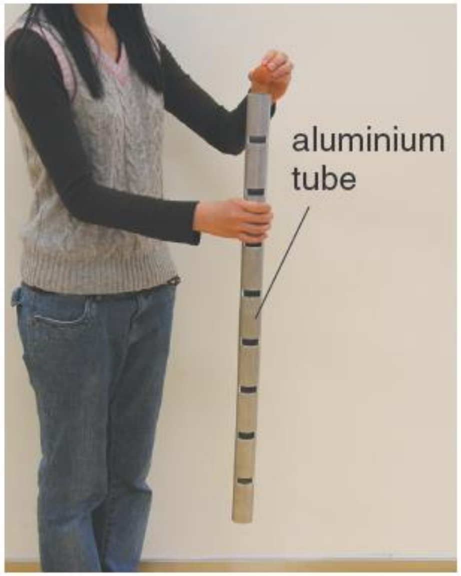
Naughty balls

Here are two balls of similar size and mass. *A* is embedded with a piece of metal and *B* a piece of magnet.



They are falling freely inside an aluminium tube.

Surprisingly, ball *B* spends a much longer time inside.



Video

5.1 Naughty ball

1 Induced e.m.f. and current

a Conductor experiencing a change in magnetic field

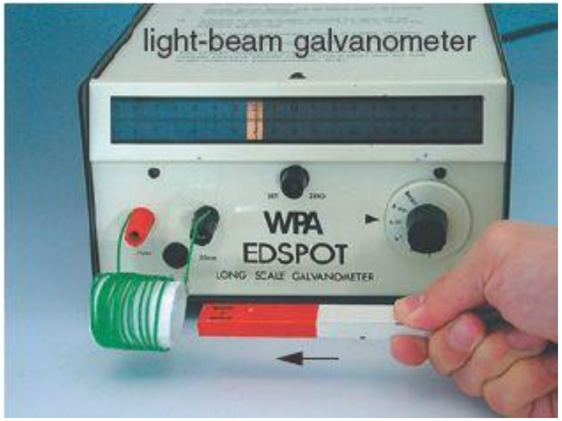
In 1831, scientists discovered that a current could be produced from a changing B-field.

This effect is called **electromagnetic induction**.

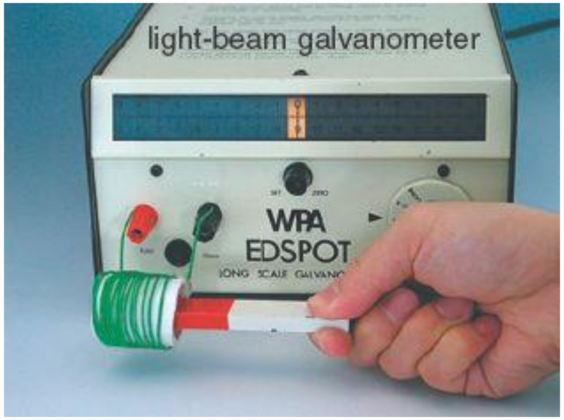
Expt 5a **Relative movement of conductor and magnet**

a Conductor experiencing a change in magnetic field

Induced e.m.f. is developed across conducting coil/wire when there is a relative motion between coil/wire and magnet.



No induced e.m.f. when conductor and magnet are relatively stationary.



a Conductor experiencing a change in magnetic field

Relative motion can be moving away from or towards each other.

$\Rightarrow$ change in B-field experienced by conductor

$\Rightarrow$ the change generates induced e.m.f.

$\Rightarrow$ drives **induced current** in a closed circuit

1 Induced e.m.f. and current

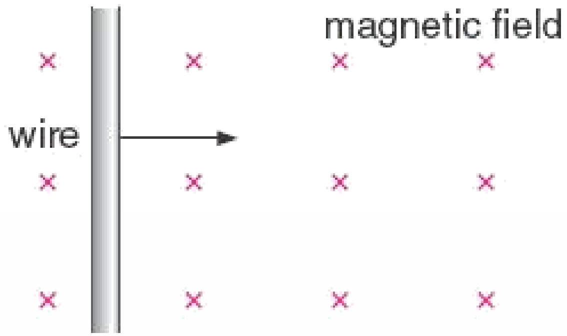
b Conductor cutting through magnetic field lines

Expt 5b

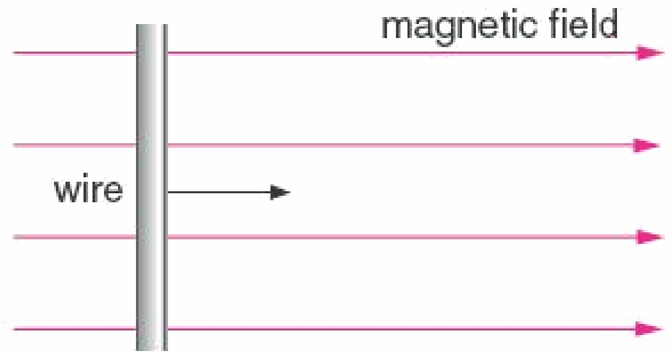
Moving a conductor across a steady magnetic field

b Conductor cutting through magnetic field lines

Induced e.m.f. can also be produced when a wire cuts through magnetic field lines.



No e.m.f. is induced when the wire is stationary or moving parallel to the magnetic field lines.



i.e. not cutting through magnetic field lines

1 Induced e.m.f. and current

c Faraday's law of electromagnetic induction

E.m.f. can be induced in a conductor when

(a) the magnetic field through it varies, or

(b) it cuts through magnetic field lines.

Magnitude of induced e.m.f. ↑ when

- moving the wire/coil or the magnet faster
- using a stronger magnet
- using a coil of more turns or ↑ the length of wire between the magnets

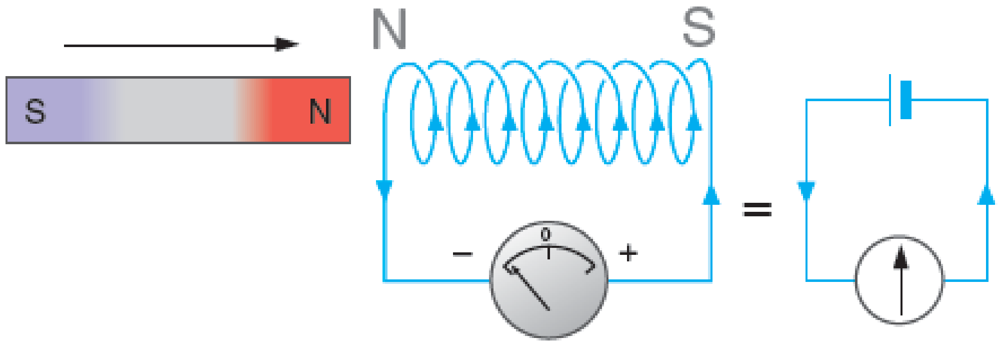
Faraday's law of electromagnetic induction:

The e.m.f. induced in a conductor is directly proportional to the rate at which the conductor cuts through the magnetic field lines, or at which the magnetic field changes.

2 Direction of induced e.m.f. and current

a Lenz's Law

When the N-pole of a magnet is pushed towards a coil, the current induced in the coil turns it into an electromagnet.

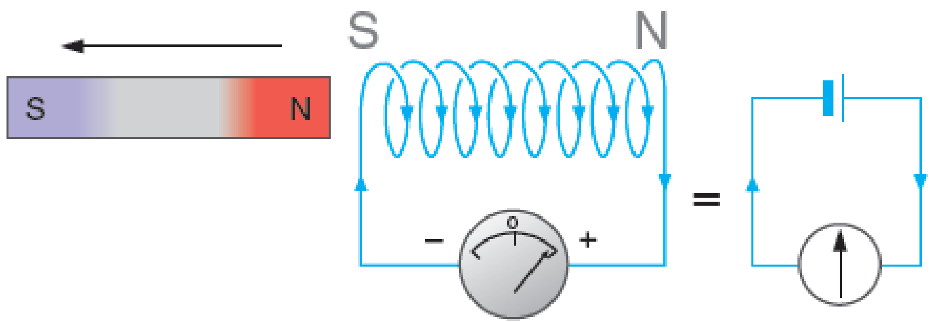


It flows in a direction as to make the end of the coil facing the magnet an N-pole.

The magnet is repelled and its motion is opposed.

a Lenz's Law

When the magnet is pulled away from the coil, the induced current in the coil makes the end of the coil an S-pole.



The magnet is attracted and its motion is opposed.

In either case, the magnet moves against a magnetic force.

⇒ work is done

⇒ transferred as electrical energy

⇒ conservation of energy is obeyed

a Lenz's Law

Lenz's law states that:

> The direction of the induced e.m.f. tends to oppose the change causing it, and does oppose it if induced current flows.

Induced e.m.f. ↑ with the rate at which B-field changes. And so does induced current in closed circuit.

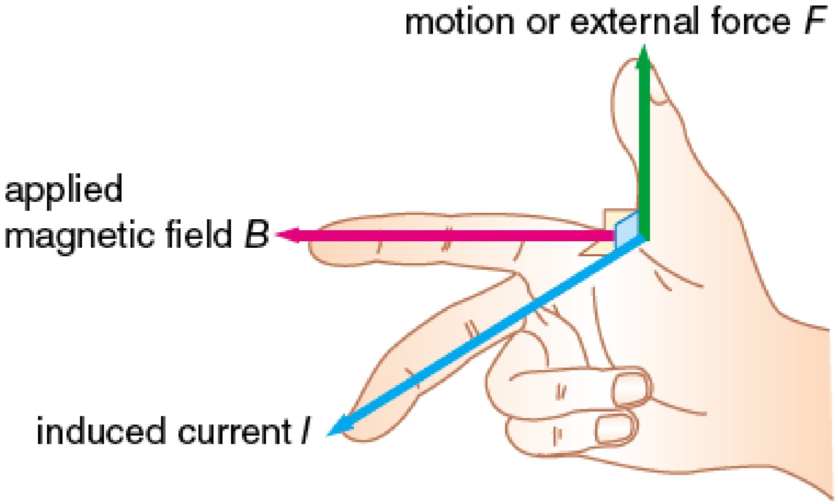
Faster change ⇒ greater opposition

Simulation 5.1 Lenz's law

2 Direction of induced e.m.f. and current

b Fleming's right-hand rule

For a wire cutting through a B-field, direction of induced current can be found by Fleming's right-hand rule.



Example 1 Using Lenz's law and Fleming's rule

b Fleming's right-hand rule

Example 2 **Current induced along a coil**

b Fleming's right-hand rule

Expt 5c

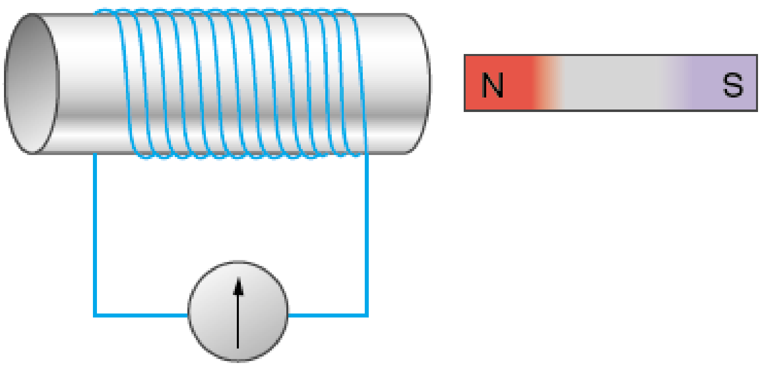
Investigating induced e.m.f. in a coil using data-logger

b Fleming’s right-hand rule

Example 3 **Magnet falling through a coil**

Check-point 1 – Q1

Which of the following movements will not result in any induced current in the coil?



A The magnet moves away from the coil.

B The coil moves away from the magnet.

C Both the magnet and the coil move towards the right together at the same rate.

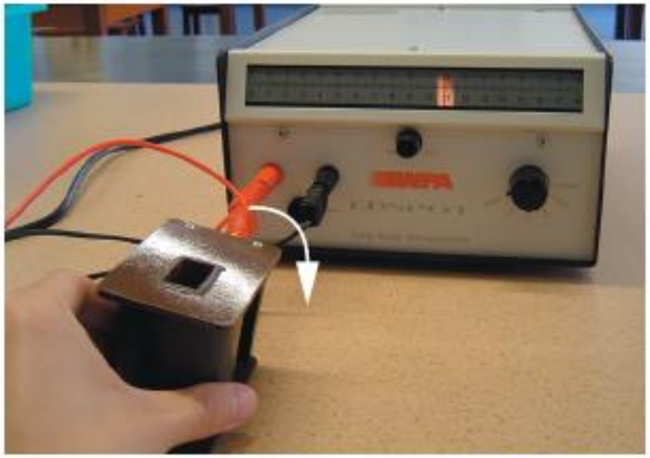
D None of the above

Check-point 1 – Q2

A 1100-turn coil is connected to a galvanometer **without** any magnets placed near it.

However, when the coil is flipped, a current is observed.

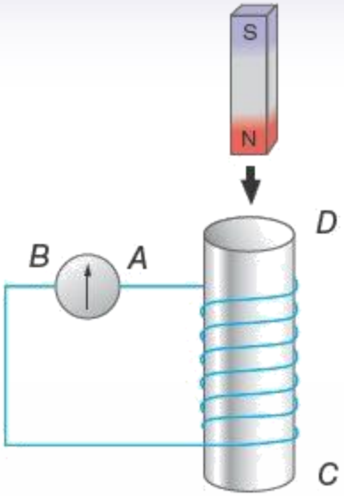
Why?



There is a small steady field of the earth which acts on the coil. When the coil is rotated, a current is induced.

Check-point 1 – Q3

The pointer of a galvanometer deflects to *A* if a current flows from *B* to *A* via the meter. What happens to the pointer as the magnet drops?



By Lenz's law, induced current flows in the coil to __oppose__ the motion of the bar magnet.

∴ N-pole is induced at __*D*__ .

According to the right-hand grip rule for solenoid, current flows from __*A*__ to __*B*__ via the meter and then the pointer deflects to __*B*__ .

3 Magnetic flux and flux density

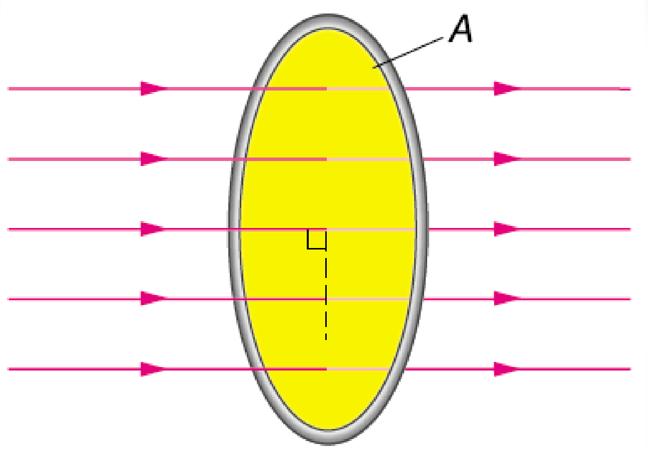
a Magnetic flux

Faraday: ‘E.m.f. is induced in a conductor either when there is a change in number of lines “linking” (passing through) it, or it “cuts” across field lines.’

Magnetic flux Φ measures the amount of magnetic field lines crossing an area.

a Magnetic flux

Consider a magnetic field *B* incident normally to a single-turn coil of area *A* (in m^2).



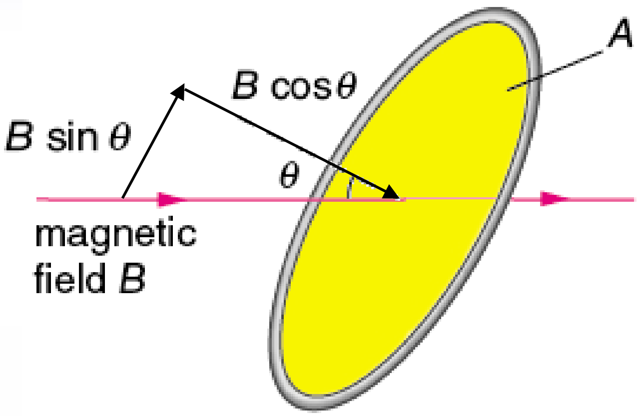
Magnetic flux Φ through that area:

$\Phi = BA$ ....(1)

Unit of Φ: **weber** (**Wb**)

a Magnetic flux

When B-field is not at right angles to the coil, only the field component ⊥ the coil (i.e. $B \cos \theta$) contributes to the magnetic flux.



$$\Phi = (B \cos \theta)A = BA \cos \theta$$

If the coil is replaced with a coil of N turns, the total magnetic flux through the coil (**magnetic flux linkage**) = $N\Phi$.

Magnetic flux linkage = $N\Phi$

3 Magnetic flux and flux density

b Magnetic flux density

Rearranging equation (1), $B = \dfrac{\Phi}{A}$

Magnetic field B can also be defined as magnetic flux per unit area

$\Rightarrow$ **magnetic flux density**

$\Rightarrow$ unit: **weber per metre squared** (**Wb m^{-2}**)
or tesla (T)

Example 4 **Calculation of flux and flux linkage**

3 Magnetic flux and flux density

c Mathematical representation of Faraday's law and Lenz's law

Faraday's law in terms of magnetic flux:

The induced e.m.f. (ε) in a conductor is equal to the rate of change of magnetic flux, or the rate of flux cutting.

$$\text{i.e. } \varepsilon = \frac{\Delta\Phi}{\Delta t}$$

c Mathematical representation of Faraday's law and Lenz's law

In fact,

$$\varepsilon = -\frac{\Delta\Phi}{\Delta t}$$

–ve sign: to include the effect of Lenz's law

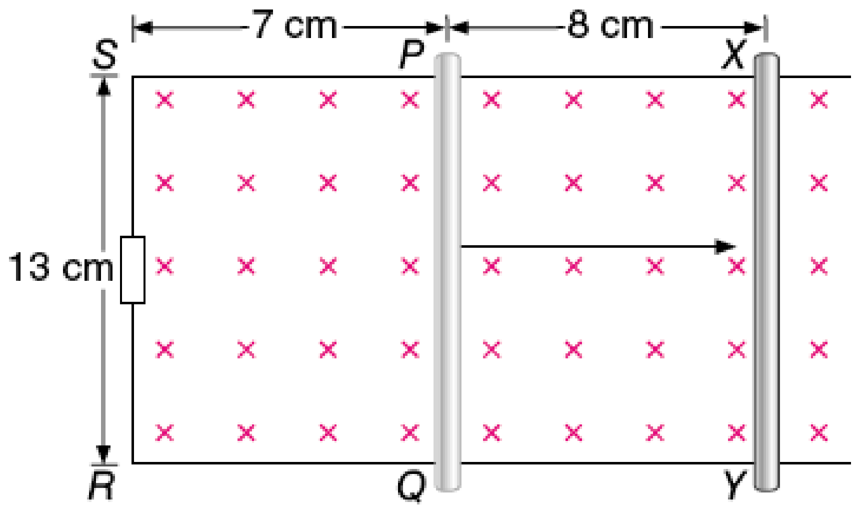
⇒ current due to the induced e.m.f. produces opposing flux change to work against the flux change causing it

For coil of N turns, $\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t} = -\dfrac{\Delta(N\Phi)}{\Delta t}$

Example 5 Rate of flux cutting

Check-point 2 – Q1

(For Q1–4) Consider a conducting rod moving along smooth metal rails in a 5-T B-field.



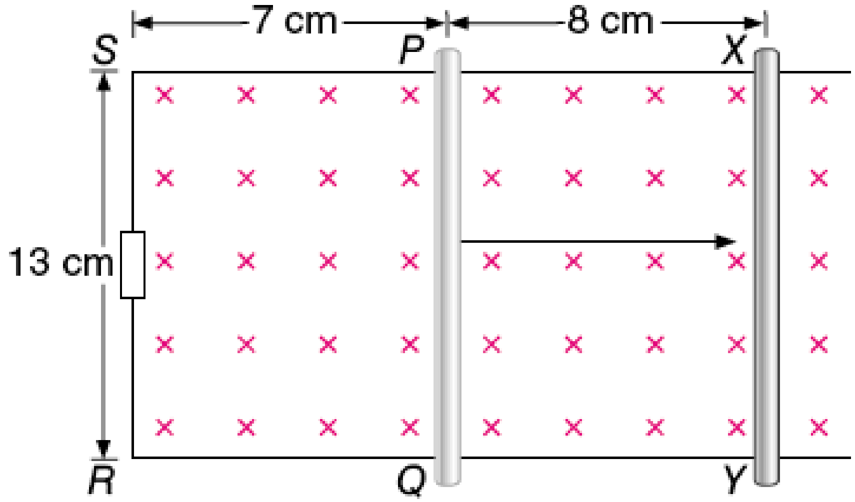
Magnetic flux through the loop *PQRS* = ?

$\Phi = BA = 5 \times 0.07 \times 0.13$

$= 4.55 \times 10^{-2}$ Wb

Check-point 2 – Q2

The rod moves with constant speed from *PQ* to *XY* in 0.5 s.

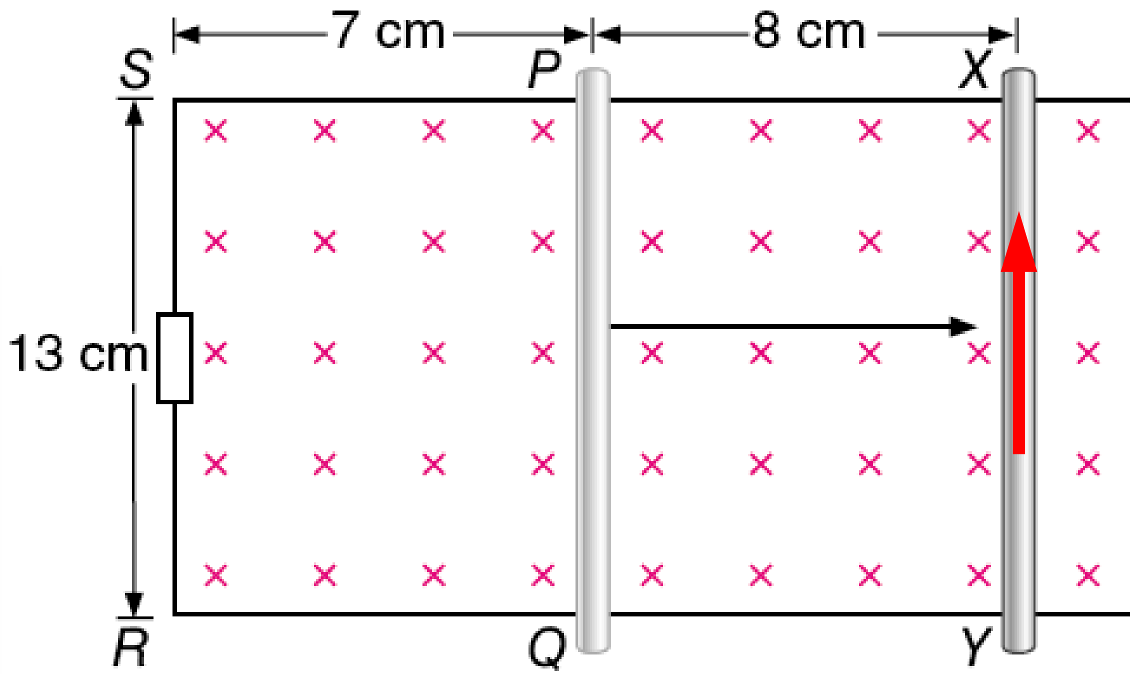


Magnitude of induced e.m.f. on the rod = ?

Magnitude of induced e.m.f.

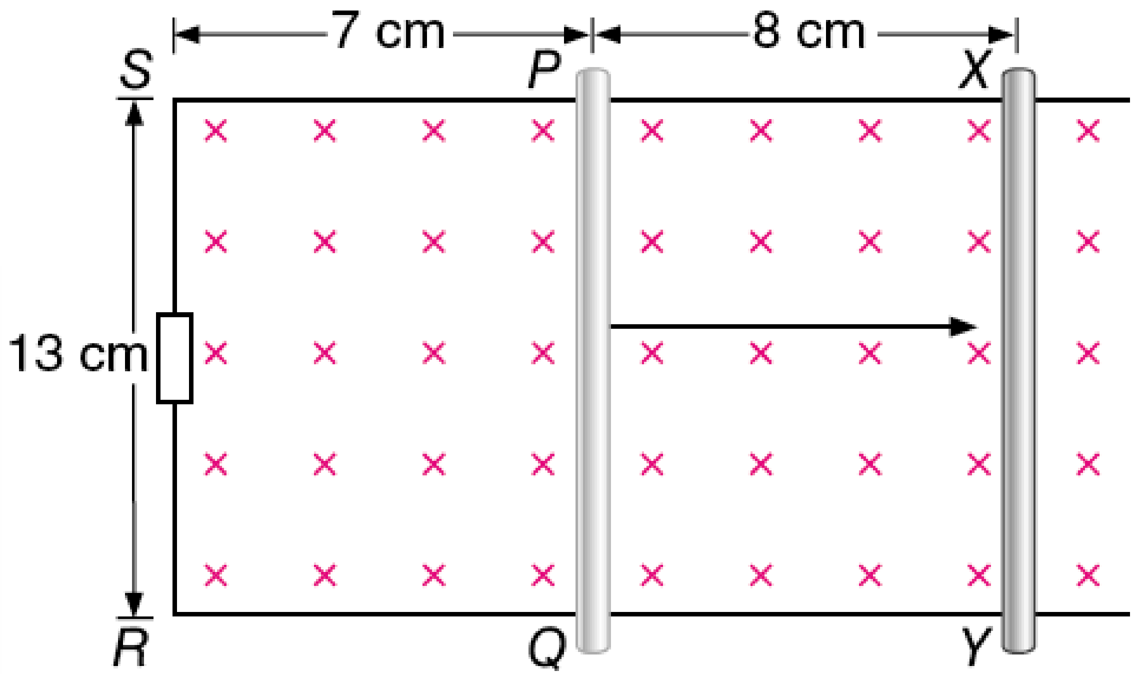
$$= \frac{\Delta\Phi}{\Delta t} = \frac{BA}{\Delta t} = \frac{5 \times 0.13 \times 0.08}{0.5} = 0.104 \text{ V}$$

Check-point 2 – Q3



Draw arrows to show the direction of the induced current.

Check-point 2 – Q4



Which end, *X* or *Y*, has a higher potential?

X

3 Magnetic flux and flux density

d Solving problems by applying Faraday's law

Example 6 Calculation of induced e.m.f.

d Solving problems by applying Faraday's law

Example 7 Induced e.m.f. across the wings of an aeroplane

d Solving problems by applying Faraday's law

Example 8 **Induced e.m.f. in an moving coil**

The End